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Provenance and reference groups of African Red Slip ware based on statistical analysis of chemical data and REE

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A B S T R A C T

African Red Slip (ARS) ware (*sigillata africana)* from three archaeological sites in northern (Oudhna, Sidi Khalifa) and central Tunisia (Henchir el Guellel) was studied by X-ray fluorescence and statistical treatment of chemical data in order to define homogeneous reference groups. The specimens from Henchir el Guellel are clearly different from those of the other two sites, which are compositionally more similar, due to their geographical vicinity. ARS ware from Sidi Khalifa is chemically very homogeneous, whereas that from Oudhna clusters into two distinct groups. The chemical correspondence with literature reference groups, based on both kiln wastes and sherds from archaeological surveys, defines new reference groups, statistically more numerous and representative. Comparisons of chemical data by neutron activation analysis on selected potsherds and clays from the surroundings of each site also identified the probable base-clays used to produce the ARS ware of Oudhna, Sidi Khalifa, and to advance some hypothesis on that used in Henchir el Guellel, thereby overcoming difficulties in assessing chemical contents of elements due to levigation processes.

1. Introduction

Terra sigillata chiara or *sigillata africana* is a type of African Red Slip Ware (ARS ware), famous in antiquity as high-quality tableware, and distributed extensively in Roman times from the last third of the 1st to the 7th century AD from North Africa, mainly from Tunisia (Hayes, 1972). ARS ware belongs to a group of red-slipped fine pottery produced in large quantities by workshops with highly organised manufacturing processes (Mackensen and Schneider, 2006), mostly in northern and central Tunisia, and described in terms of reference group compositions by Mackensen (1993). *Terra sigillata* ware, being a product of great artistic and technological skill (Lopez-Pérez, 2001), is of great interest in archaeology from the chronological and economic viewpoints, since it was very popular during Roman times and can be used to assess trading patterns (Peacock, 1982). Due to this intense distribution around the Mediterranean and across the north-western provinces of the Roman Empire (Fermo et al., 2008), ARS ware workshops probably served both regional and long-distance market demands. Although stylistic features and the specific characteristics of both ceramic paste and slip can supply information about production centres, provenance studies must be supported by analytical results and comparisons with reference groups and/or local clay materials. More specifically, in the case of *terra sigillata*, although many archaeological studies describe the stylistic features univocally identifying the production centres, constraining provenance remains very difficult, since ARS ware from various locations often shows very similar macroscopic features. Many archaeometric studies show that ceramics fired in different workshops may differ in terms of elemental chemical composition (Pollard and Hatcher, 1986; Taylor and Robinson, 1996a, 1996b; Mackensen and Schneider, 2002, 2006; Cheng et al., 2004; Feng et al., 2005; Schindler-Kaudelka et al., 1997) and that these differences are useful in distinguishing specific reference groups.

Scientific study of ceramic sherds can therefore provide important information also constraining the provenance of objects

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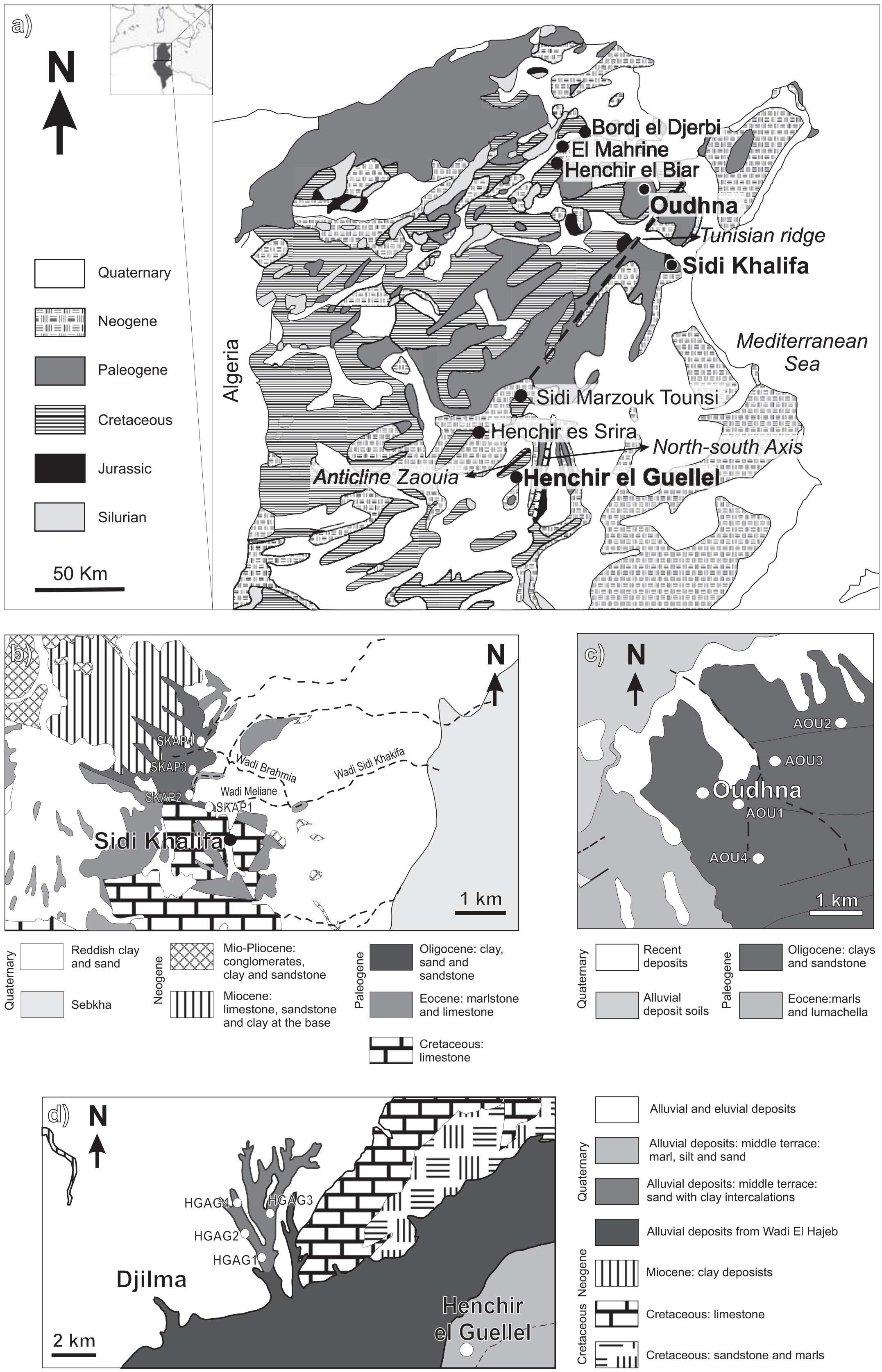

Fig. 1. a) Geographic location of Oudhna, Sidi Khalifa and Henchir el Guellel sites on the geological sketch of Tunisia. Other productive sites of Late Roman ARS ware attested in central and north Tunisia, and the ARS ware which was archaeometrically analysed before, are also reported; location of clay sampling points nearby the site of: b) Sidi Khalifa; c) Oudhna; d) and Henchir el Guellel.

Table 1
List of analysed potsherds and clay samples. For the archaeological materials, age and context of provenance (excavation, survey) are also reported.

Site	Locality	Potsherds	Clays	Topographical coordinates	Age	Context
Feradi Maeus	Sidi Khalifa	CSK21 – CSK22	SKAP1	10°24′06″N; 36°14′96″E	III–VII century AD	Survey
		CSK23 – CSK24	SKAP2	10°23′04″N; 36°14′96″E		
		CSK31 – CSK32	SKAP3	10°24′02″N; 36°14′98″E		
		CSK33 – CSK36	SKAP4	10°24′05″N; 36°15′05″E		
		CSK37 – CSK41				
		CSK42 – CSK44				
		CSK46 – CSK49				
		CSK50– CSK51				
		CSK52 – CSK54				
		CSK56				
Uthina	Oudhna	COU1,1–COU1,2	AOU1	10°11′13″N; 36°36′08″E	III–VII century AD	Excavation
		COU1,6–COU2,6	AOU2	10°12′32″N; 36°36′90″E		
		COU2,8–COU3,5	AOU3	10°11′38″N; 36°36′68″E		
		COU3,6–COU3,7	AOU4	10°11′97″N; 36°35′78″E		
		COU4,1–COU4,2				
		COU4,4–COU4,6				
		COU4,7–COU5,3				
		COU5,5–COU5,6				
Henchir el Guellel	Djelma	CHG1–CHG1,1	HGAG1	7°91′64″N; 39°19′80″E	c. 230/250 to middle V century AD	Survey
		CHG1,4–CHG1,5	HGAG2	7°91′20″N; 39°20′04″E		
		CHG1,6–CHG1,9	HGAG3	7°92′08″N; 39°20′46″E		
		CHG2–CHG2,1	HGAG4	7°91′05″N; 39°20′92″E		
		CHG2,2–CHG2,4				
		CHG2,5a–CHG2,5b				
		CHG2,6–CHG3				
		CHG3,6–CHG3,7				
		CHG4–CHG4,1				
		CHG4,8–CHG5				
		CHG6–CHG7				

of uncertain attribution (Baxter and Buck, 2000), assigning dates and rediscovering production technologies (Tite, 2003; Maggetti, 2001). Compositional data are usually treated with statistical multivariate methods, which can define compositionally homogeneous groups of sherds and describe reference groups for productive archaeological sites.

In this study, multivariate statistical analysis of geochemical data was conducted on a series of potsherds of *sigillata africana* from three archaeological sites in Tunisia, with the aim of defining whether the ceramic materials were local or imported from other areas of the country. The similar macroscopic aspect of some of the samples from the three sites prompts the question of exchanges of finished products among nearby centres. More specifically, *sigillata* ware was collected from the sites of Oudhna (the Roman city of Uthina) (Gauckler, 1897; Hayes, 1972), Sidi Khalifa (the Roman city of Pheradi Mauis) (Hayes, 1972; Carandini, 1981), and Henchir el Guellel “Djelma” (Mackensen and Schneider, 2002, 2006), the first two sites being located in north-eastern Tunisia facing the Gulf of Tunis, about 30 and 40 km south of Carthage, respectively. More in details, Oudhna extends about 5 km^2, covering a hilly plateau on the north-western side of the ridge crossing Tunisia from the south-west to north-east. Sidi Khalifa covers 40 ha on the coast, about 50 km from Oudhna, on the south-east side of the Tunisian ridge. Lastly, Henchir el Guellel is located in west central Tunisia and lies about 10 km east of Djilma, bordered to the north-west by the anticline “Zaouia”, to the east by the “north–south Axis” (Fig. 1a).

These sites were part of the Roman Empire from the 2nd century to the first half of the 7th century AD.

Archaeological evidence indicates that Oudhna was a *terra sigillata* productive centre between the late 5th and the mid-6th century (Mackensen, 1993). The finding of various potters' tools, such as punches, *pugilla*, and plaster moulds for lamps of type Hayes II B/*Atlanta X* A, as well as potsherd fragments indicates that tableware and lamps in *sigillata chiara* category D2 (Carandini, 1981) characterised by fine-textured orange paste, were the main productions (Gauckler, 1897; Mackensen, 1993). The same type of *sigillata* was also produced in the workshops of Sidi Khalifa (Fig. 1a), an active Roman centre. Macroscopically, the fine orange fabric of the *sigillata* ware from this site is indistinguishable from that of Oudhna. The occupation of this site dates from the 3rd century BC, but the city has seen its economic and social development during the Roman period. Archaeological studies indicate that the site of Henchir el Guellel can be considered the main workshop for the production of African *sigillata* type A/D (Bonifay et al., 2012; Bonifay, 2003); but also *terra sigillata* type C^{1-4} Hayes forms is here largely attested (Bonifay et al., 2005). The production of *sigillata* A/D may have started here as early as the 3rd century until the first half of the 5th century. Since C^5 Hayes forms have not been found at Henchir el Guellel, the *sigillata* production at this site ended in the mid-5th century (Pröttel, 1996). Henchir el Guellel has been not excavated until now, but intensive archaeological surveys indicate the presence of remains of kilns, and large deposits of red pottery cover an area about 200 m^2 (Peacock et al., 1990).

The occurrence of different types of *terra sigillata* in the different production centres in north and central Tunisia, on one hand reflects dispersed fabrics, attesting that each type was manufactured independently. This suggests that the *sigillata* production was not centralized and that each production centre was not specialized in the manufacturing of only one or a few types of productions. On the other hand, it is not possible *a priori* to discriminate on the basis of macrofabrics and shape, possible local trades of fine pottery, normally exported also in more distant Roman provinces (Peacock et al., 1990; Brun, 2001; Bonifay, 2003).

Many archaeometrical studies on *terra sigillata* have been done in the last decades, especially on findings discovered in consumption sites or productive workshops in various centres of the ancient Roman provinces, such as Gallia Transalpina (Picon et al., 1975; Maggetti and Küpfer, 1978; Maggetti et al., 1980; Zanco and Galetti, 2001; Zanco and Luginbühl, 2001; Brun, 2004), Gallia Cisalpina (Mirti et al., 1999; Menchelli et al., 2001; Maritan et al., 2013), Noricum (Schindler-Kaudelka et al., 1997) or even the

Italian peninsula (Picon et al., 1971; Mirti et al., 1990, 1999). But, despite the important studies on African *terra sigillata* found both in north–Africa (see for instance Taylor and Robinson, 1996a, 1996b; Schuring, 1988; Picon, 1998) and in other countries around the Mediterranean Sea (Schindler-Kaudelka et al., 1997) and the long term chemical analysis carried out by the research group at University of Lyon coordinated by M. Picon (CNRS – UMR 5138 Archéométrie et Archéologie, Maison de l'Orient et de la Méditerranée), only few archaeometric analyses, including chemical data, were published (Brun, 2001, 2004; Mackensen and Schneider, 2002, 2006). Therefore, this study aims to integrate reference groups for the *sigillata* of Oudhna and Henchir el Guellel, based on small sets of samples (Brun, 2004; Mackensen and Schneider, 2002, 2006), and to define a consistent reference group for the site of Sidi Khalifa.

A series of clay materials collected from local deposits near the three sites, was also here studied to identify possible source areas of raw materials.

2. Materials and methods

The ceramic sherds here analysed were selected with the archaeological responsible of the ceramic collection of the site, among the materials collected from the archaeological excavation at Oudhna, and during an archaeological field surveys at Sidi Khalifa and Henchir el Guellel (Table 1) carried out by the Tunisian and Spanish team. Among the materials, it was not possible to find any ceramic waste, despite the sites were productive centres of *sigillata* (Mackensen and Schneider, 2002, 2006; Bonifay, 2003; Ben Moussa, 2001), as attested by the occurrence of kilns, kiln bricks and saggars.

Sixty-one potsherds of African Red Slip (ARS) ware, "*Sigillata Africana*", dated between the 2nd and 7th centuries AD, were selected for this study. Classification of the chronologically sensitive ARS vessel form is generally feasible with J.W. Hayes' catalogue of chronologically grouped forms, which still serves as an irreplaceable source of information (Hayes, 1972). The most frequently attested forms at the studied sites are dishes, plates, bowls and some lamps. Sherds from Oudhna and Sidi Khalifa sites belongs to productions D and those from Henchir el Guellel to forms C and A/D. Most of the potsherds do not present any relief and appliqué decorations, with the exception of same fragments of sherds collected at Oudhna and Henchir el Guellel, characterised by stamped decorations. It is worth knowing that *sigillata* D is an extremely heterogeneous group, in which two main sub-categories have traditionally been distinguished, D1 and D2. Archaeological studies and recent archaeometric investigations have added new subdivisions (Bonifay et al., 2012). The category A/D is defined mainly by a relatively small repertoire of forms, with a quite homogenous appearance, in section and surface. The paste is coarser than that of the class D and C, and generally covered from a thick and glossy slip (Carandini, 1981).

As regards firing technology, all the ARS articles were fired in oxidising conditions (mode C according to Picon, 2002; Barraud et al., 1998), in large cylindrical vessels, called saggars (cassettes in Franch), which isolated them from the reducing atmosphere of the firing chamber (Bonifay, 2004), and not in kiln tubing like *italic* and *gallic sigillata* types. The finding of saggars at the studied sites indicates that they were ARS ware production centres.

Twelve samples of clay were also collected from local deposits near Oudhna, Sidi Khalifa and Henchir el Guellel (Fig. 1). More in detail, clays from Oudhna and Sidi Khalifa were sampled from the Oligocene levels (light grey clays from the "Fortuna formation"), the purity and workability of which resulted to be much better than other clays outcropping in the nearby deposits. In effect, Miocene and Mio-Pliocene clay deposits have higher content in the coarse

Table 2
Chemical composition of major, minor (expressed as oxide wt%), and trace elements (expressed as ppm) of the analysed potsherds and clay materials. Abbreviations (site): OU, SK, HG: ARS ware from Oudhna, Sidi Khalifa and Henchir el Guellel, respectively; *AOU*, *ASK*, *AHG* (italic and underlined): clay materials collected near Oudhna, Sidi Kalifa and Henchir el Guellel, respectively.

Sample		Site	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Pb	Sn	Th
Sidi Khalifa	Potsherds																								
	CSK3	SK	69.81	0.99	17.07	5.67	0.03	1.24	0.86	2.14	2.12	0.07	4.35	30	12	68	21	77	246	26	394	20	32	3	11
	CSK4	SK	73.36	0.98	16.32	5.05	0.02	1.22	0.64	0.42	1.95	0.04	1.21	24	6	62	20	93	219	26	448	20	34	3	11
	CSK5	SK	74.29	0.89	14.93	5.48	0.04	1.21	0.68	0.42	2.02	0.05	1.27	28	5	58	17	88	199	27	410	16	18	3	10
	CSK19	SK	74.27	0.93	15.39	4.88	0.02	1.16	0.56	0.62	2.12	0.05	2.29	26	7	57	18	88	205	27	426	18	19	2	9
	CSK21	SK	72.49	0.95	16.16	5.19	0.03	1.37	0.70	0.91	2.14	0.07	1.54	31	9	67	20	97	223	30	431	18	24	3	12
	CSK22	SK	73.20	0.99	16.21	5.19	0.03	1.21	0.73	0.46	1.93	0.05	1.48	26	7	61	20	90	219	27	422	18	19	3	10
	CSK23	SK	73.46	0.98	15.97	5.25	0.02	1.18	0.67	0.53	1.90	0.05	1.39	25	13	63	20	89	238	27	430	19	28	2	11
	CSK24	SK	73.88	0.89	15.10	5.25	0.02	1.19	0.81	0.54	2.25	0.06	0.86	27	5	63	18	90	196	27	431	18	22	1	11
	CSK31	SK	70.80	1.00	17.52	5.73	0.02	1.32	0.83	0.62	2.09	0.06	1.40	28	17	69	21	96	217	28	380	19	21	3	12
	CSK32	SK	71.34	0.99	17.19	5.69	0.03	1.40	0.69	0.59	2.03	0.06	1.28	30	8	67	20	96	209	30	402	19	20	3	12
	CSK33	SK	72.21	0.94	14.65	5.21	0.01	1.22	1.28	2.51	1.89	0.07	1.44	22	7	45	18	83	237	24	420	17	18	2	11
	CSK36	SK	75.59	0.86	14.15	5.02	0.02	1.13	0.72	0.49	1.96	0.06	1.43	25	5	55	17	85	212	27	444	16	20	2	11
	CSK37	SK	74.82	0.94	14.84	5.10	0.02	1.07	0.74	0.57	1.82	0.06	0.64	26	9	54	18	87	201	26	442	18	19	2	10
	CSK41	SK	70.24	0.98	17.09	5.17	0.01	1.34	0.57	2.49	2.04	0.06	1.32	30	8	64	21	98	208	28	422	20	20	3	12
	CSK42	SK	72.01	1.01	16.88	5.18	0.02	1.28	0.60	1.04	1.94	0.04	1.40	28	8	56	21	96	256	28	419	19	28	3	12
	CSK44	SK	73.10	0.92	15.74	5.50	0.03	1.26	0.75	0.58	2.06	0.07	1.20	29	7	70	18	92	189	29	409	17	19	3	11
	CSK46	SK	72.32	1.00	16.61	5.37	0.02	1.24	0.88	0.47	2.04	0.05	0.72	27	13	60	20	96	219	27	408	19	21	3	11
	CSK49	SK	71.37	1.02	17.38	5.43	0.02	1.31	0.68	0.71	2.01	0.06	1.27	29	8	59	21	95	193	28	395	19	19	3	11
	CSK50	SK	69.74	1.04	18.22	6.16	0.03	1.50	0.60	0.68	1.97	0.06	1.20	33	17	79	21	95	194	34	368	20	22	3	11
	CSK51	SK	72.81	0.92	15.67	5.50	0.03	1.32	0.62	0.94	2.12	0.06	1.52	34	1	64	19	94	213	30	429	17	18	3	10
	CSK52	SK	73.88	0.93	15.02	5.30	0.04	1.20	0.69	0.87	2.01	0.06	1.29	30	7	60	18	91	204	28	430	17	20	2	11

(*continued on next page*)

Table 2 (*continued*)

Sample		Site	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Pb	Sn	Th
	CSK54	SK	74.29	0.97	15.35	4.61	0.02	1.15	0.76	0.96	1.82	0.07	1.08	24	7	52	18	83	196	25	391	18	23	2	11
	CSK56	SK	70.36	1.00	17.82	5.65	0.02	1.37	0.76	0.87	2.09	0.06	1.25	30	8	67	22	101	237	29	382	20	23	4	11
Oudhna	COU1,1	OU	69.44	0.93	17.07	6.30	0.02	1.86	1.10	0.88	2.32	0.07	1.53	43	12	77	21	103	178	28	315	18	112	3	12
	COU1,2	OU	68.12	0.88	15.42	6.02	0.03	1.75	4.84	0.86	2.00	0.09	1.22	30	10	57	20	92	225	29	337	17	25	2	11
	COU1,6	OU	69.90	0.92	16.11	6.32	0.03	2.02	0.91	1.24	2.47	0.07	1.26	36	11	72	21	107	160	31	385	19	102	2	12
	COU2,6	OU	71.41	0.84	15.70	5.49	0.02	1.69	1.13	1.49	2.16	0.07	2.78	32	9	65	20	96	190	28	316	17	20	3	10
	COU2,8	OU	71.27	0.62	11.59	5.03	0.02	1.62	6.81	0.91	1.96	0.16	3.89	25	21	60	14	68	183	20	204	15	23	2	8
	COU3,5	OU	69.52	0.89	16.42	6.20	0.02	1.91	1.98	0.92	2.08	0.06	1.28	37	11	68	21	96	158	27	327	18	24	3	12
	COU3,6	OU	70.58	0.81	15.28	5.73	0.04	1.82	1.99	1.68	1.96	0.10	1.49	31	7	67	19	86	175	27	338	18	22	3	11
	COU3,7	OU	69.11	0.93	17.34	6.68	0.03	1.81	1.14	0.59	2.29	0.07	0.92	35	21	87	22	109	183	32	344	19	23	3	12
	COU4,1	OU	66.44	0.99	18.03	6.89	0.03	2.31	1.09	1.68	2.43	0.13	1.68	48	12	83	23	115	171	33	311	20	24	2	12
	COU4,2	OU	71.30	0.94	15.87	6.22	0.03	1.75	1.04	0.39	2.40	0.06	1.02	35	16	72	19	106	160	32	396	19	21	2	11
	COU4,4	OU	70.80	0.76	13.95	5.05	0.02	1.62	4.85	0.77	2.11	0.06	1.23	26	5	49	18	83	195	23	323	16	80	2	10
	COU4,6	OU	68.24	0.97	17.27	6.63	0.02	2.09	0.91	1.30	2.47	0.09	1.45	36	11	75	21	109	172	32	351	19	25	3	12
	COU4,7	OU	74.05	0.90	14.12	5.55	0.04	1.46	0.92	0.54	2.34	0.08	1.24	24	8	49	17	91	219	27	431	17	20	2	10
	COU5,3	OU	67.61	1.05	19.45	6.15	0.03	1.89	0.85	0.47	2.42	0.07	1.93	53	1	65	24	112	248	33	317	21	22	3	13
	COU5,5	OU	73.99	0.85	13.99	5.24	0.03	1.48	1.48	0.57	2.27	0.09	1.70	29	38	121	18	90	179	27	361	16	32	2	10
	COU5,6	OU	74.46	0.87	13.90	4.95	0.03	1.36	1.30	0.70	2.36	0.09	1.37	6	55	17	92	196	26	419	16	20	1	10	10
Henchir el Guellel	Potsherds																								
	CHG1	HG	63.32	0.94	19.12	5.71	0.03	2.78	1.14	0.89	5.93	0.13	2.02	43	36	55	25	176	171	34	232	18	24	3	12
	CHG1,1	HG	62.68	0.91	18.63	5.65	0.03	2.97	1.63	1.52	5.86	0.13	1.69	37	25	66	24	173	186	30	225	17	22	2	12
	CHG1,4	HG	62.27	0.84	16.67	5.11	0.05	3.65	4.32	1.41	5.51	0.16	3.61	39	22	48	21	149	275	27	218	15	18	3	10
	CHG1,5	HG	60.18	0.85	18.35	6.13	0.05	3.49	3.05	1.67	6.04	0.19	2.63	52	24	58	24	167	199	28	195	16	19	3	11
	CHG1,6	HG	61.07	0.86	17.94	5.61	0.04	2.96	3.11	2.21	6.05	0.15	1.88	42	26	59	23	165	503	30	225	16	22	4	12
	CHG1,9	HG	61.51	0.89	17.31	5.18	0.04	3.13	2.12	4.11	5.57	0.14	1.85	46	24	70	22	164	175	32	220	17	21	3	12
	CHG2	HG	56.80	0.82	18.79	6.86	0.06	4.34	4.67	1.72	5.73	0.20	2.86	50	29	58	25	175	315	29	158	16	17	2	12
	CHG2,1	HG	58.97	0.82	18.38	6.30	0.05	3.73	3.80	1.92	5.86	0.17	3.12	42	22	59	24	167	463	29	182	16	18	3	12
	CHG2,2	HG	63.25	0.94	18.40	5.04	0.03	2.84	1.62	2.01	5.72	0.15	1.66	43	27	53	24	172	195	33	233	18	20	3	12
	CHG2,4	HG	59.26	0.79	17.61	6.29	0.05	3.71	4.11	2.18	5.81	0.17	2.50	39	25	55	22	165	263	27	169	15	16	2	10
	CHG2,5a	HG	58.99	0.83	18.24	6.40	0.05	3.73	4.07	1.70	5.81	0.17	2.59	40	36	56	23	165	416	26	164	15	14	2	11
	CHG2,5b	HG	58.86	0.81	18.22	6.09	0.05	3.92	4.68	1.47	5.74	0.17	3.65	39	23	51	23	167	722	26	158	15	14	2	11
	CHG2,6	HG	64.03	0.86	17.32	5.20	0.04	2.87	2.51	1.52	5.54	0.12	1.65	36	1	58	22	160	219	30	258	17	18	3	11
	CHG3	HG	63.26	0.90	17.98	5.39	0.04	3.11	2.57	0.77	5.87	0.10	2.33	38	23	58	23	160	283	30	230	17	16	3	11
	CHG3,6	HG	63.87	0.94	19.28	5.68	0.03	2.68	0.78	0.65	5.96	0.12	2.05	44	28	52	25	183	145	34	228	19	18	2	13
	CHG3,7	HG	65.68	0.96	16.64	5.45	0.03	2.82	2.11	1.04	5.18	0.08	1.49	40	22	84	20	155	210	31	233	16	20	2	10
	CHG4	HG	62.76	1.07	18.49	5.42	0.03	2.81	2.75	0.75	5.77	0.14	3.50	42	33	53	22	166	808	31	208	17	20	2	11
	CHG4,1	HG	62.95	0.87	17.64	5.61	0.05	3.24	3.05	0.82	5.66	0.11	1.94	37	23	47	22	160	181	29	236	16	20	3	12
	CHG4,8	HG	62.68	0.96	17.56	6.28	0.03	2.91	2.70	1.00	5.78	0.10	4.52	44	55	59	20	162	342	27	200	16	17	3	11
	CHG5	HG	56.89	0.85	20.05	6.96	0.06	4.56	3.68	0.55	6.21	0.19	1.58	50	32	61	26	184	158	29	153	17	18	3	12
	CHG6	HG	60.13	0.79	17.30	5.97	0.06	4.18	5.26	0.62	5.54	0.15	3.25	40	33	60	21	159	433	29	215	16	14	3	10
	CHG7	HG	63.58	0.97	19.44	5.66	0.03	2.67	0.78	0.70	6.06	0.12	2.82	40	47	61	24	179	147	33	213	18	19	3	12
	Clays																								
	SKAP1	ASK	69.89	0.72	19.17	6.36	0.03	1.11	0.66	0.35	1.65	0.06	9.79	25	1	58	15	76	203	20	305	15	34	3	6
	SKAP2	ASK	64.50	1.10	22.56	6.25	0.02	2.08	0.46	0.80	2.18	0.07	13.46	32	16	65	23	107	144	28	239	22	19	3	11
	SKAP3	ASK	69.21	1.26	20.66	4.40	0.01	1.39	0.57	0.41	2.03	0.05	11.16	25	5	46	22	88	130	28	353	24	17	4	11
	SKAP4	ASK	74.92	0.97	15.11	3.37	0.01	1.64	0.28	1.73	1.92	0.05	10.47	19	5	35	20	93	139	22	329	20	17	3	10
	AOU1	AOU	57.03	0.67	10.28	5.60	0.03	1.94	22.53	0.53	1.38	0.04	20.50	21	4	34	10	48	359	21	266	11	11	1	7
	AOU2	AOU	71.57	0.94	15.19	5.81	0.02	1.99	1.06	3.05	2.31	0.09	9.56	26	4	74	15	87	141	33	410	16	15	2	10
	AOU3	AOU	82.16	0.76	11.24	1.63	0.01	0.87	0.43	0.81	2.05	0.03	6.18	14	1	21	12	73	133	23	501	15	13	4	9
	AOU4	AOU	75.02	0.95	14.91	3.13	0.02	1.87	0.67	2.93	2.33	0.09	8.58	17	2	36	16	92	114	28	449	18	15	3	10
	HGAG1	AHG	69.04	0.39	5.53	1.82	0.02	0.90	19.54	1.03	1.70	0.04	15.17	8	2	25	9	50	173	12	237	6	8	1	3
	HGAG2	AHG	59.51	0.64	12.45	5.31	0.06	4.77	12.00	0.62	4.28	0.35	14.75	27	15	33	12	95	1236	30	144	9	17	2	6
	HGAG3	AHG	71.18	0.68	13.07	4.33	0.11	2.31	1.25	1.75	5.17	0.16	25.25	14	1	19	9	66	200	18	243	6	7	1	6
	HGAG4	AHG	49.40	0.73	16.06	5.23	0.06	10.61	12.85	0.54	4.45	0.08	22.27	20	17	34	16	124	84	21	132	11	9	2	7

sandy-sized fraction, occur in thinner layers and with intercalation of conglomerate, sandstone and limestone. As for Henchir el Guellel site, clays were collected from alluvial deposits forming the "Quaternary middle terrace", composed mainly of sand and clay. The selection of the collection points was done considering the present pottery production and the indication of local potters. The material was in these cases sampled from the present extraction surface. These clays, collected from geological deposits not exploited at the present, were extracted from a variable depth from the surface (between 20 and 40 cm), after the upper soil was removed and a clean clay was accessible.

All the potsherds and clay specimens were reduced to powder in a mechanical mortar grinder equipped with corundum bowl and pestle, after removal of the surface layer of potsherds to avoid possible contamination. About 5–10 g of powder was produced from each potsherd. Quantitative chemical analyses of major and minor (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5) and trace elements (Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Pb, Sn, Th) were carried out by X-ray fluorescence (XRF) on a Siemens SRS3400 spectrometer (WDS, rhodium target X-Ray tube, 60 kV) at the GENERIC laboratory of the SPIN centre of the Ecole Nationale Supérieure des Mines de Saint-Etienne, France. Major chemical elements were determined on beads, obtained by mixing 0.3 g of calcined powder (heated for 24 h at 960 °C), 0.3 of $LiNO_3$ and 5.4 g of $Li_2B_4O_7$, and then melting the mixture in a platinum alloy crucible at 1100 °C in a muffle furnace. The "fundamental parameters" method was used to determine the matrix correction coefficients from intensities measured on a series of 42 geostandards (SY2, SY3, MRG1, GR, GA, GH, BR, MICAFE, MICAMG, DRN, UBN, BXN, DTN, VSN, GSN, FKN, GLO, ANG, BEN, MAN, AL1, IFG, ACE, ZWC, JG1, JG1a, JG2, JG3, JB1, JB1b, JB1a, JB2, JB3, JR1, JR2, JA1, JA2, JA3, JF1, JF2, JP1, JGb1). Trace and rare earth elements (REEs) were determined on pellets, obtained by pressing powdered samples with an organic binder (type C wax, from Hoechst). The intensity of the rhodium Compton peak was used to correct the matrix effect. The R Project for Statistical Computing was used to explore the compositional variation matrix, according to the method proposed by Buxeda i Garrigós (1999). Chemical data were then processed with standard statistical tools such as Principal Component Analysis (PCA) and cluster analysis (CA) using Statgraphics® Centurion XVI. Major elements content was normalized to a constant 100%, in order to get a better intercomparability of the element concentration, and to compare our chemical data with those of Mackensen and Schneider (2002, 2006), also normalised to 100 wt%.

Raw data were standardised, according to procedures designed by Vitali and Franklin (1986), and Baxter (1999), by log-transformation (to base 10) in order to avoid misclassifications due to the different orders of magnitude and range of variation of the variables (Fermo et al., 2008). PCA, a well-known pattern recognition technique, was used here to display and analyse the structure of multivariate data by projecting them into a reduced hyperspace defined by the first significant principal components (Baxter and Buck, 2000; Baxter, 1994, 2006). CA was adopted to define homogeneous chemical groups within the dataset. For further information about source areas of raw materials used for ceramic production, the chemical data of the potsherds were statistically compared with those obtained on clay materials collected near the sites.

In addition to multivariate analysis of bulk chemical compositions, comparisons of normalised abundances of rare earth elements (REEs) and other trace elements to the average crust, obtained by neutron activation analysis (NAA) on sets of ceramic sherds from each site (4 from Henchir el Guellel, 3 from Oudhna, and 4 from Sidi Khalifa) and on the all the clays collected from nearby, was applied here to overcome difficulties in identifying chemical composition due to levigation during production. Neutron activation analysis was carried out at the Laboratoire Pierre Süe (CEN Saclay, France) following Chayla et al. (1973). Samples were reduced to powder in an agate mortar and coated in aluminium foil. They were then irradiated in a 150-mg cadmium crucible in the Osiris nuclear reactor at Saclay (France) for about 12 h under an epithermal neutron flux of the order of 2.2 * 1014 n cm^{-2} sec^{-1}. International standards (GSN: calc-alkaline granite; BEN: alkali basalt, mainly used to correct chromium) were also irradiated in the same conditions. After about a week, a first 3000-s count was made to determine short-period radioisotopic elements (Mo, La, Sm, W, U). A second count from 10,000 to 40,000 s (after one month) provided radioisotopic elements of longer period: Sc, Cr, Co, Ni, Zn, Rb, Sr, Zr, Sb, Cs, Ba, Ce, Nd, Eu, Tb, Yb, Hf, Ta and Th.

3. Results and discussion

The multivariate statistical analysis was performed on the studied potsherds and clay materials, excluding Cu, CaO and Na_2O from the variables, because of their high values of the total sum of variance ($\tau_{.i}$) (15.35, 11.42, 7.56, respectively), as obtained from the compositional variation matrix determined for all the analysed elements. Even though high values of $\tau_{.i}$ are not indicative

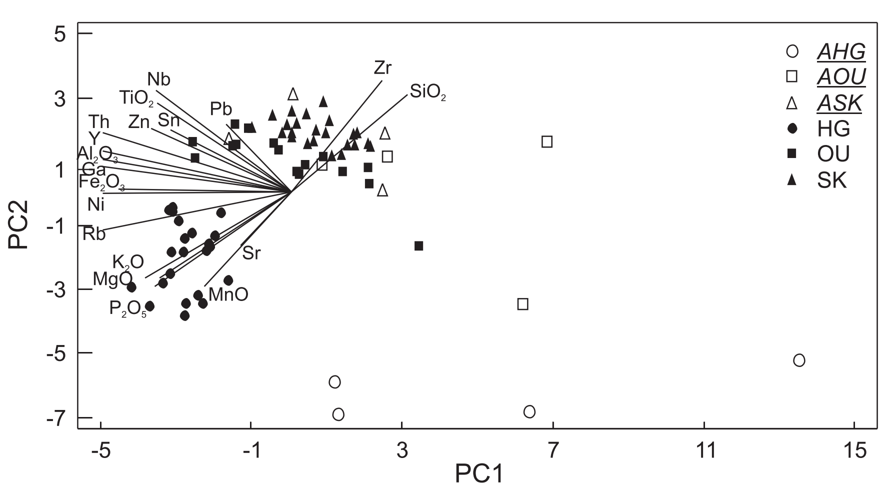

Fig. 2. Score and loading plot of the principle component 1 and 2 (PC1 vs. PC2), representing 42% and 31% of the total variance, performed on the subcomposition SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, K_2O, P_2O_5, Ni, Zn, Ga, Rb, Sr, Y, Zr, Nb, Pb, Sn, and Th of all the studied potsherds and clay materials. Abbreviations: OU, SK, HG: ARS ware from Oudhna, Sidi Khalifa and Henchir el Guellel, respectively; *AOU*, *ASK*, *AHG* (italic and underlined): clay materials collected near Oudhna, Sidi Kalifa and Henchir el Guellel, respectively.

exclusively of contamination, but can be related also to compositional heterogeneities between different production sites, or within the same production to the variations in the clays as occurred in nature or as superimposed by different degree of levigation process, these elements were not considered in the multivariate statistical treatment of data. Comparisons of potsherds from Oudhna, Sidi Khalifa and Henchir el Guellel (Table 2) show that the samples from the last site are clearly different from those of the other two. In the PCA score plot (Fig. 2), they show negative values of both PC1 and PC2, being discriminated from the other sites mainly due to higher Fe_2O_3, MgO, K_2O, Rb, Sr and Ni content. Potsherds from Oudhna plot at low values of PC1 and positive values of PC2, and show lower variance than those from Sidi Khalifa. Only one sample from Oudhna was isolated from all the others, at positive PC1 values and negative PC2. Only some of the clays from near Oudhna and Sidi Khalifa cluster with the potsherds of these two sites, whereas those from near Henchir el Guellel clearly differ from all the others. These data were also confirmed by CA: the dendrogram of Fig. 3

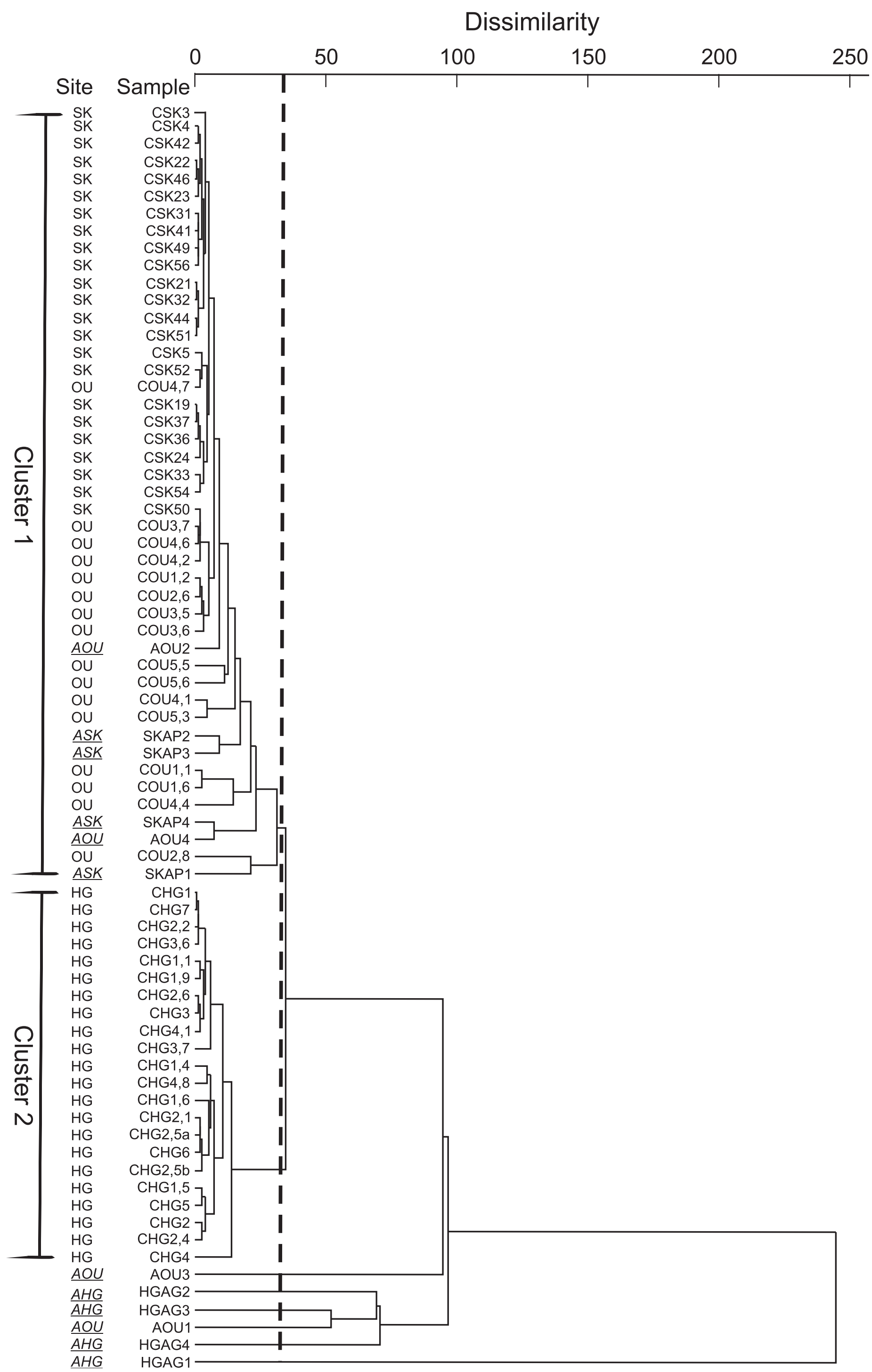

Fig. 3. Dendrogram obtained from the hierarchic cluster analysis using the square Euclidian distance and the average linkage method, on the subcomposition SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, K_2O, P_2O_5, Ni, Zn, Ga, Rb, Sr, Y, Zr, Nb, Pb, Sn, and Th of all the studied potsherds and clay materials. Abbreviations: OU, SK, HG: ARS ware from Oudhna, Sidi Khalifa and Henchir el Guellel, respectively; *AOU*, *ASK*, *AHG* (italic and underlined): clay materials collected near Oudhna, Sidi Khalifa and Henchir el Guellel, respectively.

shows that samples from Henchir el Guellel have a higher dissimilarity level with respect to those of the other sites. It is interesting to note that, although clustering together, ARS ware from Sidi Khalifa tends to diverge from that from Oudhna (Fig. 3). Detailed analysis of Fig. 3 shows that one sample from Sidi Khalifa (CSK 50) and one from Oudhna (COU4,7) cluster with those from Oudhna and Sidi Khalifa, respectively, probably representing traded objects. Some of the clays collected from near Oudhna (AOU2, AOU4) and Sidi Khalifa (SKAP1, SKAP2, SKAP3, SKAP4) plot in the same cluster of potsherds found in these sites, indicating that they represent the materials used to produce ARS ware there. Some clay samples (AOU1, AOU 3, HGAG1, HGAG2, HGAG3, HGAG4) show high dissimilarity levels, indicating that they are compositionally very different from most of the population and may be viewed as outliers.

PCA and CA (Figs. 2 and 3) both clearly show that ARS ware from Henchir el Guellel forms a very distinct group with respect to the other two. This result was not unexpected since, considering these samples as locally produced, the clay comes from different geographical regions and different geological contexts (Fig. 1). ARS ware from Sidi Khalifa and Oudhna form two homogeneous, compositionally more similar groups, due to their closer geographical proximity. In addition, the chemical composition of the sherds indicates that most ARS ware was prepared with non-calcareous quartz-rich clay, matching literature data on such ware from northern and central Tunisia (Mackensen and Schneider, 2002, 2006). Since clay composition may change greatly over distances of tens or hundreds of km, i.e., practically throughout the regions in which ARS ware was probably produced (Taylor and Robinson, 1996b), comparisons are required with the *site reference groups* of ARS ware previously defined in northern and central Tunisia. Although a large number of *sigillata africana* potsherds from 4 kiln sites in Tunisia (El Mahrine, Oudhna, Sidi Khalifa and Sidi Marzouk Tounsi) (Taylor and Robinson, 1996a), as well as from Carthage in Tunis (Tunisia) and San Sisto Vecchio in Rome (Italy) (Schuring, 1988) was analysed by neutron activation analysis (NAA), the authors did not published the raw data or at least the means of the composition of the groups. Therefore, the chemical data here obtained were compared only with those published by Brun (2004) and Mackensen and Schneider (2002, 2006). These authors analysed various samples collected at Oudhna (23 potsherds), Mahrine (41 potsherds), Henchir el Biar (19 potsherds), Bordj el Djerbi (16 potsherds) in northern Tunisia (geographically very closed to each other), and Henchir es-Srira (the modern Henchir Esskhira) (6 potsherds), Henchir el Guellel (14 potsherds) near Djilma, and Sidi Marzouk Tounsi (44 potsherds) in central Tunisia (Fig. 1). These sites all date between the 2nd and 7th century AD, and each forms distinctive compositional reference groups (Mackensen and Schneider, 2002, 2006). The PCA score plots of all studied samples, excluding the above-mentioned outliers (Fig. 4), and those published in the literature show that ARS ware from Sidi Marzouk Tounsi (SMT) and Henchir el Guellel (HG + RGHG: samples here analysed and those forming the reference group of Mackensen and Schneider, 2006; respectively) both clearly differ from the other sites, having higher TiO_2, Fe_2O_3, Al_2O_3, MnO, alkali, Nb, Rb and Ni contents, and lower SiO_2. ARS ware from northern Tunisian workshops is compositionally quite similar and partially overlaps at more negative values of PC1 and positive PC2.

These differences can also be observed in the CA dendrogram (Fig. 5), in which three clusters clearly appear: cluster 1, formed of ARS ware from Henchir el Guellel (HG + RGHG); cluster 2, composed of ARS ware from Sidi Marzouk Tounsi (SMT); and cluster 3, grouping samples from all the northern sites and Henchir es-Srira. Outliers isolate from the other samples for the lower Al_2O_3 and TiO_2 contents (COU2,8), the higher P_2O_5 and Sr (Ma1), Zn (BD3, HB18, HB19), and SiO_2 (AOU4, SKAP4).

Since the samples from Henchir el Guellel studied here cluster with the reference group published by Mackensen and Schneider (2006) (RGHG), a clearly defined reference group at this site is established and is now more representative in terms of statistics, so that it can be used in provenance studies. Sample Dji1, from Henchir el Guellel (Mackensen and Schneider, 2002), shows high dissimilarity level with the other potsherds from the same site, anyway clustering with Henchir el Guellel. It may therefore be a local variant, although it cannot be excluded that it is a case of importation from a site in the same region, for which clay of similar composition was used. The chemical composition of ARS ware from Henchir el Guellel shows great variability, mostly expressed by variable MgO, K_2O, MnO, Rb, and Ni contents (Table 2). These can be related to the use of clay from various deposits, fitting the results of Mackensen and Schneider (2002), or to different intensity of levigation process on compositionally analogous clays.

CA also showed that ARS ware from Sidi Marzouk Tounsi forms a separate cluster, with a lower dissimilarity level than the ware from sites further north, rather than with those of central Tunisia (Fig. 5).

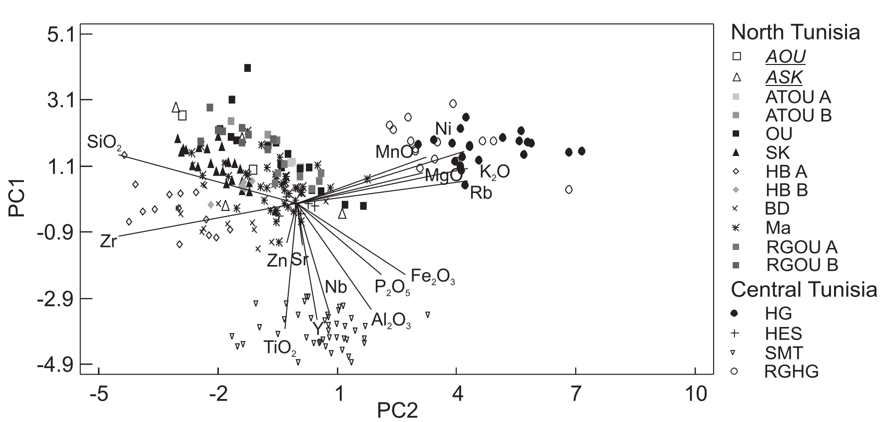

Fig. 4. Score and loading plot of the principle component 1 and 2 (PC1 vs. PC2), representing 35% and 29% of the total variance, performed on the subcomposition SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, K_2O, P_2O_5, Ni, Zn, Rb, Sr, Zr, and Nb of ARS ware analysed in present study and on that studied by Brun (2004) and Mackensen and Schneider (2002, 2006). Abbreviations: ARS ware: BD: Bordj el Djerbi; HB: Henchir el Biar; HES: Henchir es Srira; Ma: Mahrine; SMT: Sidi Marzouk Tounsi; RGHG: reference group Henchir el Guellel; RGOU: reference group Oudhna (Brun, 2004; Mackensen and Schneider, 2002); ATOU: samples attributed to Oudhna (Brun, 2004); HG: Henchir el Guellel analysed in this study; OU: Ohudna analysed in this study; SK: Sidi Khalifa analysed in this study. Clays from: *AHG*: Henchir el Guellel; *ASK*: Sidi Khalifa. Group (A) and (B) as distinguished in literature.

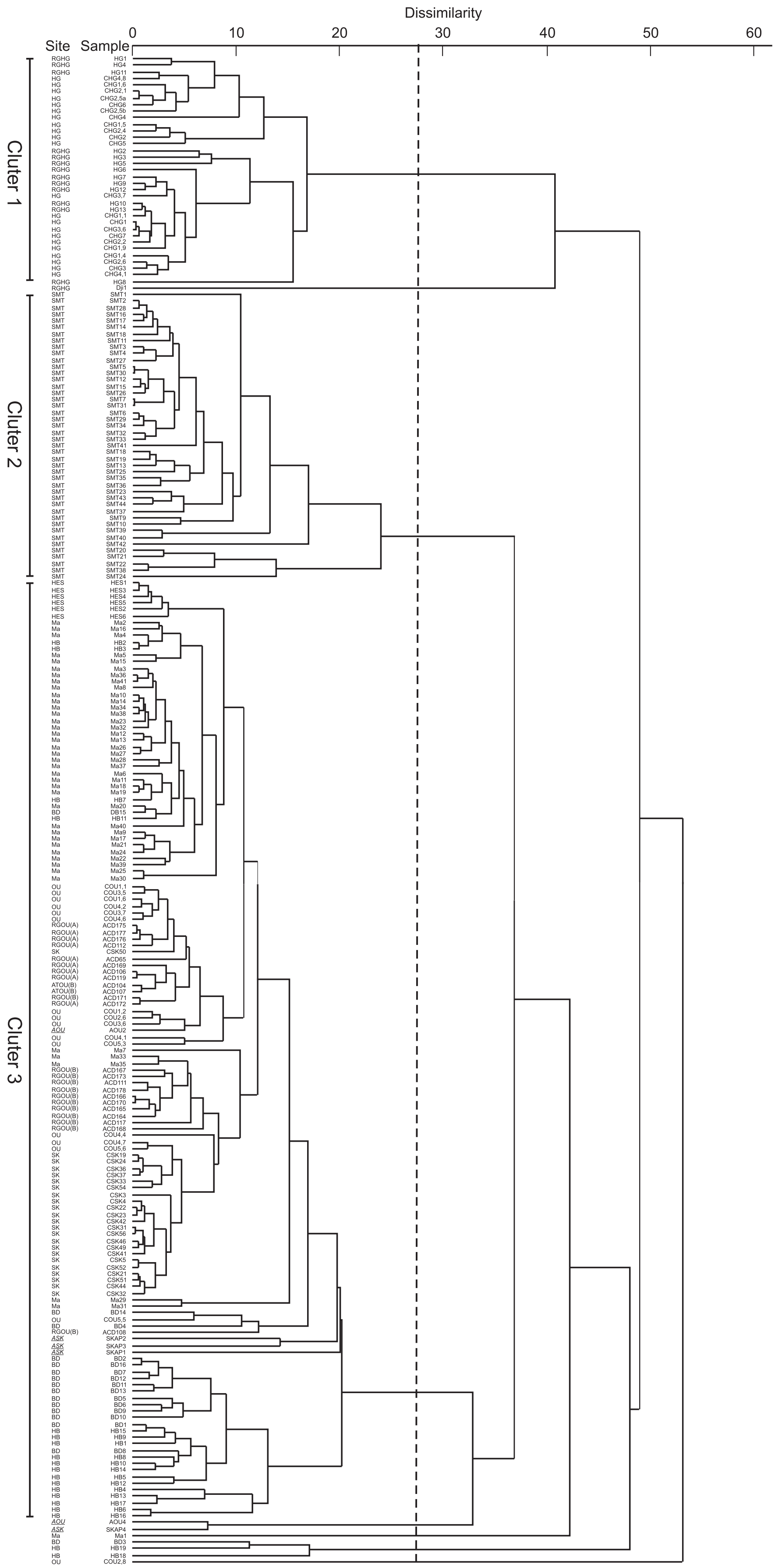

Fig. 5. Dendrogram obtained by hierarchic cluster analysis (average linkage method, square Euclidian distance) performed on the subcomposition SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, K_2O, P_2O_5, Ni, Zn, Rb, Sr, Zr, and Nb of the ARS ware analysed in present study and on that studied by Brun (2004) and Mackensen and Schneider (2002, 2006). Abbreviations: ARS ware: BD: Bordj el Djerbi; HB: Henchir el Biar; HES: Henchir es Srira; Ma: Mahrine; SMT: Sidi Marzouk Tounsi; RGHG: reference group Henchir el Guellel; RGOU: reference group Oudhna (Brun, 2004; Mackensen and Schneider, 2002); ATOU: samples attributed to Oudhna (Mackensen and Schneider, 2002); HG: Henchir el Guellel analysed in this study; OU: Oudhna analysed in this study; SK: Sidi Khalifa analysed in this study. Clays from: *HG*: Henchir el Guellel; *AOU*: Oudhna; *ASK*: Sidi Khalifa. Group (A) and (B) as distinguished in literature.

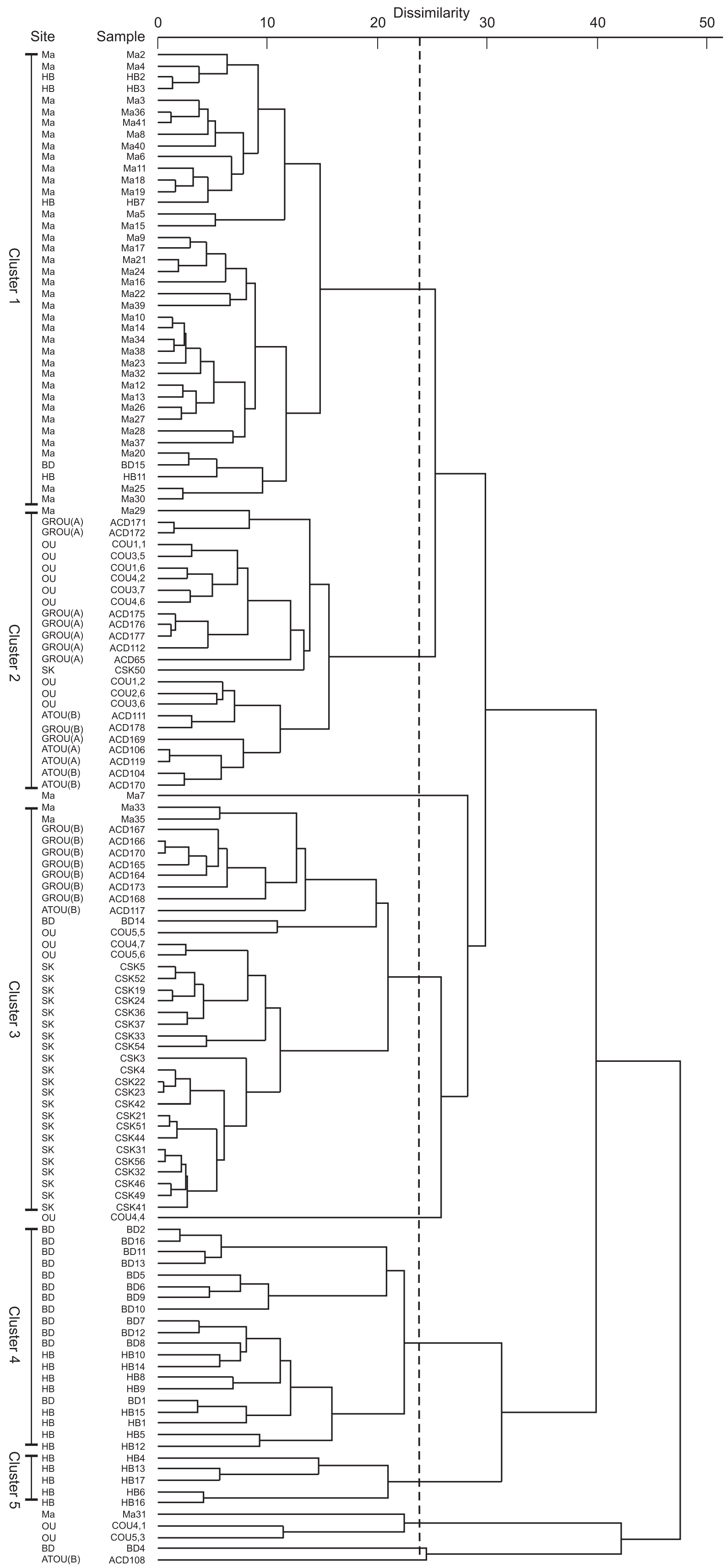

Fig. 6. Dendrogram obtained by hierarchic cluster analysis (average linkage method, square Euclidian distance) performed on the subcomposition SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, K_2O, P_2O_5, Ni, Zn, Rb, Sr, Zr, and Nb of the ARS ware analysed in present study and on that of northern Tunisia sites studied by Brun (2004) and Mackensen and Schneider (2002, 2006). Abbreviations: BD: Bordj el Djerbi; HB: Henchir el Biar; Ma: Mahrine; RGOU: reference group Oudhna (Brun, 2004; Mackensen and Schneider, 2002); ATOU: samples attributed to Oudhna (Brun, 2004); OU: Oudhna analysed in this study; SK: Sidi Khalifa analysed in this study. Group (A) and (B) as distinguished in literature.

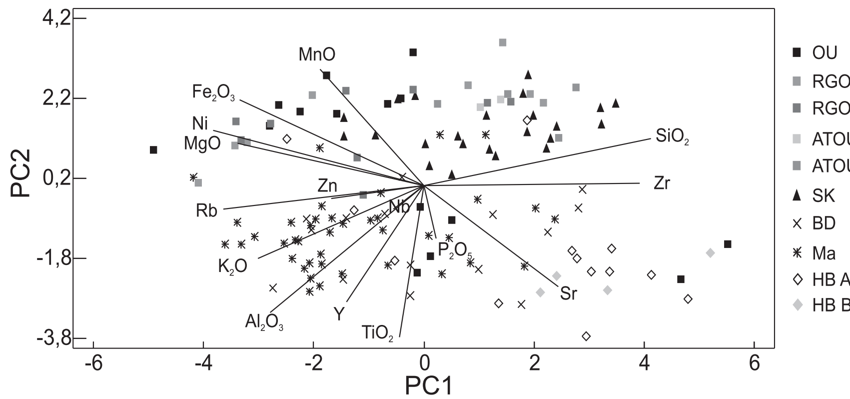

Fig. 7. Score and loading plot of the principle component 1 and 2 (PC1 vs. PC2), representing 33% and 23% of the total variance, performed on the subcomposition SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, K_2O, P_2O_5, Ni, Zn, Rb, Sr, Zr, and Nb of the ARS ware analysed in present study and on that of northern Tunisia sites studied by Brun (2004) and Mackensen and Schneider (2002, 2006). Abbreviations: BD: Bordj el Djerbi; HB: Henchir el Biar; Ma: Mahrine; RGOU: reference group Oudhna (Brun, 2004; Mackensen and Schneider, 2002); ATOU: samples attributed to Oudhna (Brun, 2004); OU: Oudhna analysed in this study; SK: Sidi Khalifa analysed in this study. Group (A) and (B) as distinguished in literature.

The samples from Henchir es-Srira, the local provenance of which was demonstrated by Mackensen and Schneider (2006), have no geochemical similarity with samples from other sites in central Tunisia (Henchir el Guellel and Sidi Marzouk Tounsi), but do show compositional similarity with those from the north (Sidi Khalifa, Oudhna, Henchir el Biar, Mahrine, Bordj el Djerbi). This might be related to the use of Paleogene clays, locally available (Fig. 1), with analogous chemical composition in all these sites, although the use of a Neogen clayey material cannot be excluded. This compositional similarity was also previously observed by Bonifay et al. (2012). Differences between ARS ware from Henchir es-Srira and the other central Tunisian sites could be due to use of clay coming from different geological levels, such as the Cretaceous and the Quaternary deposits outcropping near Sidi Marzouk Tounsi and Henchir el Guellel.

To ascertain whether ARS ware production sites in northern Tunisia can be discriminated on the basis of chemical composition, all ceramic sherds from Henchir el Guellel, Sidi Marzouk Tounsi and Henchir es-Srira were removed from the statistical treatment of data. The resulting dendrogram shows that ARS ware plots in five distinct clusters (Fig. 6). Cluster 1 is formed of potsherds from Mahrine and a few from Henchir el Biar (HB2, HB3, HB7, HB11) and one from Bordj el Djerbi (BD15); cluster 2 of potsherds from Oudhna comprising also all the potsherds of reference group A, one of group B as defined by Mackensen and Schneider (2006), and a few attributed by Brun (2004) to group A and B, and one form Sidi Khalifa (CSK50). Cluster 3 contains potsherds from different sites (Sidi Khalifa, Oudhna, Mahrine and Bordj el Djerbi), which tend to fall into two groups, the first comprising potsherds from Oudhna (reference group B and few samples here analysed) and a few from Mahrine (Ma33, Ma35) and Bordj el Djerbi (BD14), and the second of potsherds from Sidi Khalifa and two from Oudhna (COU4,7, COU5,6). Samples from Oudhna divide into two subgroups, partly falling in clusters 2 and 3, due to the higher silica content of samples in the group B, probably the result of the greater amount of fine sand in the potsherds and therefore of a less intensive levigation process (Mackensen and Schneider, 2002; Cuomo and Caprio, 1985). ARS ware from Bordj el Djerbi and some from Henchir el Biar group together in cluster 4, whereas cluster 5 is formed only of samples of the reference group A from Henchir el Biar. Some outliers can also be identified (Ma7, COU 4,4, Ma31, COU4,1, COU5,3, BD4, ACD108). These results were confirmed by the PCA score plot (Fig. 7), in which the Oudhna samples cover over a large PC1 interval due to the high chemical variability of this group, with two subgroups (A and B, the latter high in SiO_2). ARS ware from Sidi Khalifa is isolated from the other sites, although it does show a certain similarity with that of Oudhna type B, whereas *sigillata* from Henchir el Biar, Bordj el Djerbi, and Mahrine tends to form isolated clusters, richer in Sr and Zr, in TiO_2, and in K_2O, Al_2O_3, Y and Rb, respectively. Only a few samples of these sites fall in the distribution clouds of Oudhna and Sidi Khalifa. The difficulty of clearly distinguishing between some sites, such as Oudhna and Sidi Khalifa, and Henchir el Biar and Bordj el Djerbi, is due to site proximities and perhaps also to the use of clays of very similar composition, probably coming from sources belonging to the same geological formation. Potsherds plotting into the cluster formed mainly by samples from another site, can represent importation cases.

Part of the present study also involved identifying the possible clay used to produce ARS ware at the three sites of Oudhna, Sidi Khalifa and Henchir el Guellel. Multivariate statistical comparisons among the ware and clay (Figs. 2 and 3) clearly indicates the lack of any compositional similarity between potsherds and clays from Henchir el Guellel, and the impossibility of finding the source area of the raw materials used to produce them, whereas all the clays from near Sidi Khalifa (SKAP1, SKAP2, SKAP3, SKAP4) and some from Oudhna (AOU2, AOU4) cluster with the potsherds (Figs. 2 and 3) from these two sites, indicating that they were probably the raw materials used in the *sigillata* production there. Compositional differences may be attributed to several causes, including levigation of clay during working (Kilikoglou et al., 1988). Selection and mixing of clays from different sources, to give specific properties to the resulting pottery, cannot be excluded *a prior*i. This process may complicate direct comparisons between naturally occurring clays and finished pottery (Pollard and Heron, 1996).

In order to identify the base-clays for the ARS ware of the three sites, data from neutron activation analysis on selected potsherds and all the clay specimens were compared (Table 3). REEs are geochemically immobile and their patterns may therefore be used to trace the provenance of pottery (Lee, 2002; Jia et al., 2004). Multi-element distribution curves normalised to the average continental crust supplied interesting results. The distributions of clay specimens from Henchir el Guellel (in Fig. 8a are reported only the two clays which show higher geochemical affinity with potsherds) differ slightly from those of ARS ware from the same site, especially in the case of clay HGAG4, which has generally lower concentrations of all REEs and trace elements (Fig. 8a), but shows very similar

patterns. Some elements have higher (Sr) and lower (Co, Ni) concentration. Since the general pattern is quite similar, we advanced the hypothesis that a clay, lower in carbonate content with respect to those here analysed, was used. More specifically, since the clays were here collected in the Quaternary alluvial deposits, derived from the accumulation of sediments from the weathering of Neogene clays and the Cretaceous limestone, sandstone and marls, the trace elements and REEs pattern of clays HGAG2 and HGAG4 may mainly preserve the signature of the Neogene clay deposits. Therefore, the clay used in this production was probably collected from the nearby Neogene formation, although this hypothesis needs to be supported by further analysis.

Very interesting is the clear-cut correspondence between the trace elements trends in ARS ware from Oudhna and Sidi Khalifa and two clay samples (AOU2, ASKP2) collected from nearby areas (Fig. 8b and c). These clays, and others, turned out to have bulk chemical compositions close to that of the ARS ware from Oudhna and Sidi Khalifa (Figs. 2 and 3). Despite changes perhaps due to the use of clays with a naturally higher quantity of quartz (probably coarser in grain-size) in some of the *sigillata* produced at Oudhna, the final product had a trace elements signature very similar to that of the clay used to produce them. Although the Oudhna samples may be divided into two groups according to bulk chemical composition, as suggested by Brun (2004) and Taylor and Robinson (1996a), the trace elements of one samples of group A and two of group B were similar, corresponding to that of clay AOU2. This may be related to the use of clay materials from the same geological level, but with a different content of quartz, related to the natural heterogeneities in the raw clay deposit, or caused by a different grade of levigation.

This preparation process, considered to be extensively applied in producing ARS ware, may have caused important changes in the bulk chemical composition of the original material. However, since levigation would mainly have removed the aplastic inclusions making up the sandy-sized fraction, mainly prevalent quartz and subordinate feldspars, muscovite, microcline and biotite due to the prevalence of Paleogene and Neogene sandstone rocks in Sidi Khalifa and Oudhna (Fig. 1), REEs concentrations were not greatly affected in terms of trends, but only show general concentration effects. REEs analysis has been most appropriately applied to wares made of well-levigated homogeneous clays (e.g., Taylor and Robinson, 1996a), for which REE-bearing minerals are mainly concentrated in phases other than sand-sized inclusions.

4. Conclusions

Multivariate analysis of a series of potsherds from three archaeological sites in central and northern Tunisia, Henchir el Guellel, Oudhna and Sidi Khalifa, considered to be production centres for ARS ware, and comparisons with clays collected near the three sites, demonstrate that most of the potsherds were locally produced. ARS ware from all three sites was compositionally consistent with the reference groups of Brun (2004) and Mackensen and Schneider (2002, 2006). However, as these groups are based only partly on pottery from kiln contexts, comparisons with locally available materials was necessary to constrain their definite origin. Multivariate analysis was indispensable in verifying chemical similarities or dissimilarities according to many variables. The levigation process used to prepare the clays in the ARS ware production may have determined substantial compositional changes, due to the separation of the coarse grain-size fraction, but did not affect the REEs patterns. Therefore, the comparison of the REEs signature of clays and potsherds allow to identify the raw materials used in the ceramic production of Oudhna and Sidi Khalifa.

As for the ARS ware from Oudhna, Brun (2004) and Taylor and Robinson (1996a) identified two distinct productions, on the basis of multivariate analysis of major, minor and trace elements, and attributed them to the use of two different clays. But, considering the results obtained here, these two productions seems to be connected either to the use of analogous clays coming from the Oligocene deposits, differing in the sand-sized fraction, or to the intensity of the levigation process done on the same base-clay. Moreover, the comparison of both the bulk chemical composition and the REEs patterns of a clay specimen from the surroundings of

Table 3
Chemical composition of trace and rare earth elements, expressed in ppm, as obtained by NAA of some representative potsherds and clays from Oudhna, Sidi Khalifa and Henchir el Guellel. Abbreviations as in caption of.Table 2

Sample		Site	Sc	Cr	Co	Ni	Zn	Rb	Sr	Zr	Mo	Sb	Cs	Ba	La	Ce	Nd	Sm	Eu	Tb	Yb	Hf	Ta	W	Th	U
Potsherds	CSK3	SK	15	110	13	29	70	70	234	397	1	1	4	395	37	80	31	6	1	1	3	10	2	1	12	2
	CSK32	SK	16	116	15	29	65	89	205	456	1	0	6	247	44	95	31	8	2	1	3	12	2	2	13	3
	CSK41	SK	16	121	12	27	62	92	205	444	1	0	6	276	43	88	31	7	2	1	3	12	2	2	13	3
	CSK56	SK	17	116	19	32	92	87	221	342	1	1	7	251	46	105	44	8	2	1	3	9	2	2	13	2
	COU1,1	OU	15	118	15	33	87	96	176	344	2	1	6	310	43	95	35	8	2	1	3	9	2	2	13	3
	COU1,2	OU	15	107	13	28	71	89	240	370	1	1	6	375	43	94	33	8	2	1	3	10	2	2	12	3
	COU5,5	OU	12	94	14	26	103	81	166	386	2	1	5	328	36	79	28	6	1	1	3	10	1	3	11	3
	CHG1,9	HG	15	76	15	31	61	144	200	284	1	1	8	451	37	89	34	7	1	1	3	7	1	2	13	3
	CHG2,3	HG	15	80	17	34	79	147	164	246	1	1	8	423	43	90	36	7	2	1	3	6	1	2	12	5
	CHG2,4	HG	15	76	16	34	59	145	372	177	1	1	7	383	39	78	28	7	1	1	3	5	1	2	11	3
	CHG3,6	HG	16	87	14	36	65	157	135	236	1	1	7	430	44	93	35	8	2	1	3	6	2	2	13	3
Clays	SKAP1	ASK	10	80	9	19	58	71	226	421	1	1	5	268	38	63	24	4	1	0	2	11	1	1	7	2
	SKAP2	ASK	17	128	18	32	61	91	146	330	1	0	6	212	51	100	31	7	2	1	3	9	2	2	13	3
	SKAP3	ASK	19	144	13	31	70	110	158	235	1	0	8	181	53	108	39	8	2	1	3	6	2	1	14	2
	SKAP4	ASK	11	94	6	17	38	80	114	371	1	0	5	239	40	79	34	5	1	1	2	10	2	2	12	2
	AOU1	AOU	10	69	16	21	52	56	357	353	4	0	4	437	30	68	22	5	1	1	3	9	1	13	9	3
	AOU2	AOU	15	101	16	29	113	94	138	444	2	1	6	309	42	97	45	8	2	1	3	11	2	2	13	3
	AOU3	AOU	11	78	5	13	43	69	140	503	1	0	3	350	35	74	24	5	1	1	3	13	1	2	10	2
	AOU4	AOU	12	89	13	17	51	82	108	514	1	0	5	333	39	80	29	6	1	1	3	13	1	1	11	3
	HGAG1	AHG	5	27	4	4	32	54	202	333	1	0	10	342	15	32	12	3	1	0	2	8	1	0	5	1
	HGAG2	AHG	10	51	20	31	64	95	2084	211	3	1	5	349	28	56	22	5	1	1	2	5	1	1	8	3
	HGAG3	AHG	6	28	4	10	20	55	173	260	1	0	7	226	21	42	18	4	1	0	2	7	1	1	5	1
	HGAG4	AHG	11	60	8	20	45	119	82	143	2	0	5	245	29	53	24	5	1	1	2	4	1	2	9	3

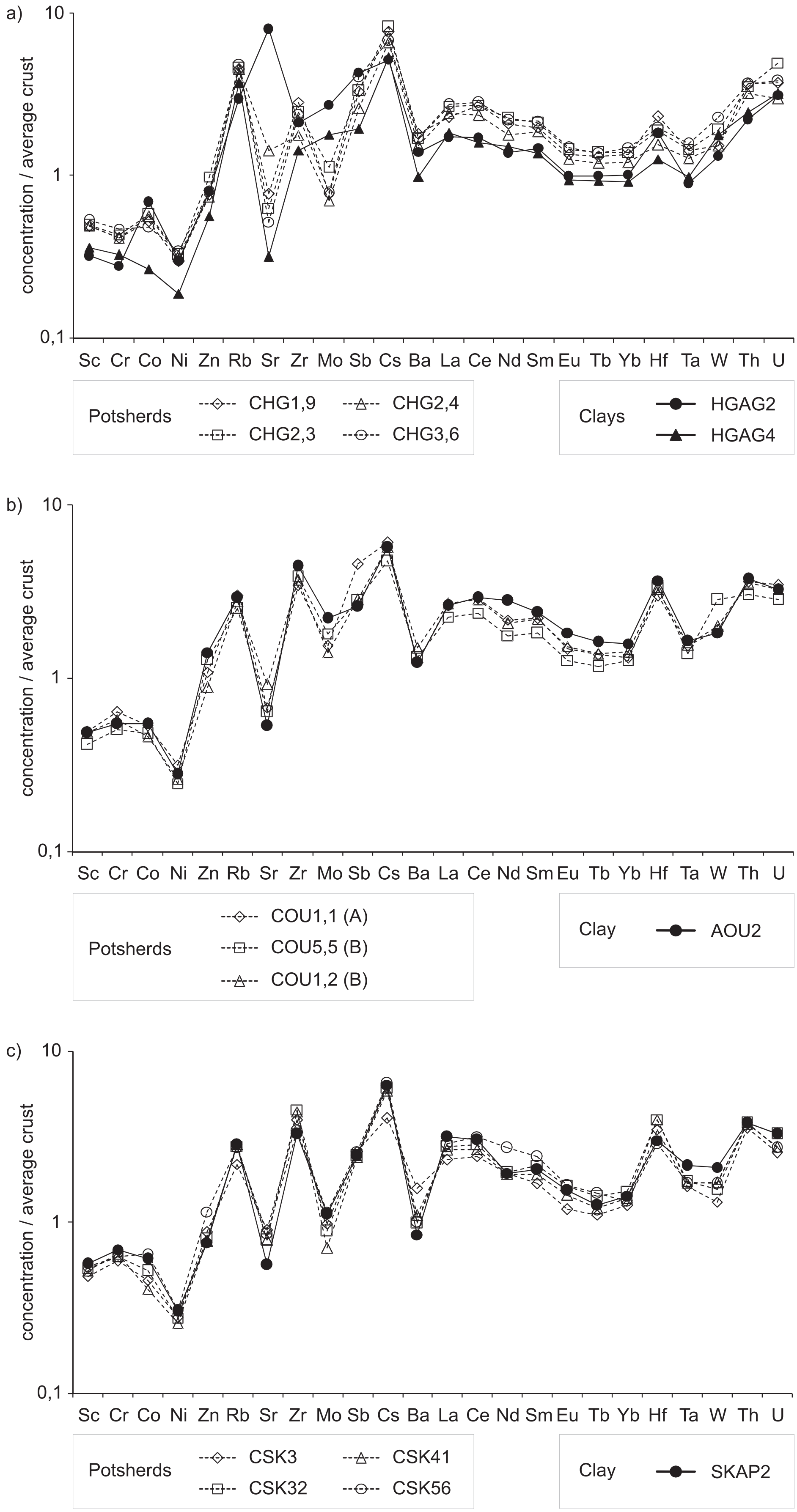

Fig. 8. Normalized elemental distribution curves of trace elements and rare earth elements (REEs) of clays collected near a) Henchir Guellel, b) Oudhna and c) Sidi Khalifa, and some selected representative ARS potsherd from the three sites.

Oudhna with selected potsherds, compositionally representative of the studied samples, clearly indicate that the pottery was locally produced.

In the site of Sidi Khalifa, the composition of the ARS ware is consistent with that of some clay specimens collected nearby, indicating also in this case that the pottery was locally produced.

Despite none of the clay materials collected near Henchir el Guellel site show bulk chemical composition similar to that of the potsherds, REEs patters allowed to advance the hypothesis that the possible base-clays was supplied from local Neogene deposits.

A few cases of importation were found among the studied samples, and their provenance was constrained by comparison with the reference groups of other central-northern Tunisia production centres, demonstrating that ARS ware was also very limited traded between established production centres in Tunisia. But, the very little number of importation cases shows how this ceramic production was intended for a local use and probably to be exported to other regions of the Roman Empire, despite the lack of archaeometric evidences for these three sites.

Finally, the chemical analysis of this study allowed to establishing statistically more consistent reference groups for the three sites of Oudhna, Sidi Khalifa and Henchir el Guellel.

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